Air Traffic Control System Requirements

Federal Aviation Agency
Air Traffic Service

March 1963

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SUBJECT: Air Traffic Control System Requirements - March 1963

FROM : Director, Air Traffic Service

TO : All Recipients

The complexity of the air traffic control system has grown phenomenally in the last decade. The point has been reached where the mere addition of people to assist in the present task will not significantly contribute to the resolution of these complex problems.

I am convinced that we must look toward simplification of the system if we are to provide ● ffectiv, ● rrlc. efficiently. Certainly the basic operational requirements can be stated in [illegible] terms. It is only when considering the procedural methods which must be employed to fulfill operational requirements that complexities start to pyramid.

This booklet reflects an initial exploration and discussion of basic ATC requirements as ● tad in the preface. This booklet does not represent approved FAA policy, but is written to stimulate ATS thinking in the development of firm, ● pacific individual requirements. Additional copies may be obtained from AT-40.

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Preface

Decisions made today cut the pattern that will be followed a decade hence. We cannot afford the luxury of cutting patterns which are not based on complete understanding and knowledge of the immediate and long term consequences. Action predicated on the treatment of symptoms must be augmented with concentrated effort to remedy the underlying cause producing the symptoms. Lasting relief cannot be found in any other manner.

In this document an effort has been made to penetrate through the exterior surface of well known system deficiencies in order to gain some insight into what lies hidden in the basic fundamentals. It is for this reason that many topics associated with the over-all ATC/NAV system appear to be slighted. It is our conviction that without attacking and solving the real threat of airspace exhaustion, the tremendous volume of airspace being gobbled up by the very small segment of the total aeronautical activity, we cannot hope to adequately provide proper utilization of our natural resources in airspace for the common benefit of all. On the other hand, if the airspace can be efficiently and sparingly used in providing the ground based air traffic control service to those operations demanding it for safety reasons, more aircraft can be provided this service while at the same time releasing vast areas of airspace for other users. It takes but a glance at a chart to realize the completeness with which airspace has been allocated and designated as control area for ATC use. In high activity areas, routes or airways overlie one another inextricably intermixed with ingress and egress routings at terminals.

Recognition of those factors which play an important role in fixing the capabilities, as well as limitations of the system today, can pay off handsomely in the determination of items for improvements. Future goals predicated on stated objectives in terms of airspace utilization are outlined, not in the sense of disregarding the present system in being, but in the sense of providing direction of present as well as future efforts toward improved system capability.

It is emphasized that this document is not an endorsement of any particular air traffic control or navigational element, or system, which offhand appears to be capable of meeting some of the stated operational requirements as outlined herein. It is, however, intended to show the urgent need of early intensive effort toward the design, development, and implementation of an ATC-NAV system capable of providing effective and efficient services based on specific goals and objectives in terms of airspace utilization. Recognizing that a period of 10 to 15 years will be required to bring any new ATC-NAV system into operational status, we cannot afford to postpone the initiation of this longer range effort toward a future system any longer. It is also essential that we continue with in-service improvements to our present systems, to make available for early use, all the potential benefits within the practical capability of the existing environment and equipments.

It is hoped that the material in this document will contribute to a better understanding of the subject by the layman as well as those specializing in particular elements of the total system, but particularly those having responsibility or interest in properly meshing all the interrelated elements into a composite whole.

It will be used by Air Traffic Service as a guide and yardstick to analyze and measure the total effect that any proposal, whether an in-service improvement item or a complete system design, will have on air traffic control capability and efficiency.

The text is supplemented by selected appendixes for those readers interested in additional supporting material.

Introduction

In response to a request from President Kennedy, a special Task Force was established to conduct a study of the safe and efficient utilization of airspace. This study known as Project Beacon was completed in October 1961. It was submitted to the White House by Federal Aviation Agency Administrator N. E. Halaby on November 1, 1961.

The President has asked the Administrator to carry out those recommendations of the Report which will move the airways program forward rapidly and efficiently. Under the provisions of the FAA Act of 1958, the Federal Aviation Agency is charged with the responsibility for the development of plans and policies with respect to the use of the navigable airspace in order to insure the safety of aircraft in flight and persons and property on the ground. In order to discharge these responsibilities, the Administrator is authorized to acquire, operate, and maintain air navigation facilities, to prescribe rules and regulations governing the flight of aircraft, and to provide the facilities and personnel for the regulation and protection of air traffic.

The foregoing mandate is outlined in Section 307 of the FAA Act. The Act gives the FAA Administrator considerable power and authority over the utilization by the public of the national airspace At the same time, in other sections of the Act, Congress has officially recognized the public right of freedom of transit through the navigable U.S. airspace. Further, in the Declaration of Policy contained in the Act, the Administrator is directed to consider the requirements of national defense.

The basic purpose of air traffic control is to provide for the safe and efficient use of the airspace. Presently, two methods are employed to provide protection from the hazard of collisions. Air Traffic Rules, Part 60, of the Civil Air Regulations contain provisions for "see and be seen" type of aeronautical activity wherein the pilots are responsible for collision avoidance. It also provides for Instrument Flight Rule type of operation wherein the collision avoidance is the responsibility of the air traffic control organization.

Both types of operntion very often occur in the same airspace since the determination of which rules apply depends on the weather conditions encountered during flight. "See and be seen" rules apply to IFR flights whenever the weather encountered is equal to or better than those specified in the Rules. This often results in a dual responsibility--air traffic control having responsibility for separation of IFR flights as they relate to each other, while the pilots of IFR flights must assume the responsibility for separation as they relate to the "see and be seen" aircraft.

It is of utmost importance that continuing review of "see and be seen" flight rules is made to assure that they are effective and realistic in view of the ever changing conditions created by advancements in aircraft design, performance and traffic density.

The primary function of the ATC system is to separate aircraft, i.e., to prevent collision between aircraft and to expedite aircraft movements. A secondary function is to provide the aeronautical public with all assistance possible to contribute toward the safe and orderly conduct of flight activities. To perform this function, and yet meet the requirements of national defense while recognizing the public right of free transit, is a task which requires careful planning and judicious use of power and authority.

Theoretically, the ideal ATC system would be one in which the flying public is protected against collision at all times and yet be permitted complete freedom in the use of airspace at all times. This ideal is impossible of attainment.

In actual practice, the present system functions as an arbiter in the sense that if more than one user wants to utilize a given portion of airspace simultaneously, the system makes a decision and one or both of the users is somewhst penalized by having his flight path adjusted to the extent necessary to assure collision avoidance. In practical application, the system is unable to allow absolutely free transit of the airspace due to the conflicting demands made on the airspace.

In order to perform its function the ATC system must, of necessity, impose certain operational and equipment requirements on the users. It requires adherence to certain rules and regulations designed to minimize the probability of mid-air collision. To acquire the data necessary for separating aircraft, the system also imposes airborne equipment requirements on users.

The operational and equipment requirements imposed by the system must undergo a continuous study to ensure that these requirements are reasonable and justified. The airborne equipment requirements must also be reviewed, not only to determine what needs to be added to the cockpit, but also to determine what equipment is superfluous and can be eliminated.

In trying to achieve the optimum system, there are three basic guidelines which must be kept in mind:

1. The system must always strive toward permitting free transit of the airspace and must impose no restriction on this right unless absolutely essential to the public interest.
2. The requirements imposed on the users by the system must have a minimum economic and operational impact.
3. The total cost of procuring and operating the system must be consistent with the value of the system to the national welfare.

SECTION I

USER Requirements

While there have been many efforts to collect and catalogue user requirements, we believe one summary statement covers them all. Airspace users would like to have an air traffic control system which would permit them to depart at a time and place of their choice, fly to a destination, or conduct a mission, utilizing climbouts, routes, altitudes, and descents with no delay or interference from other air or surface vehicles. It should be recognized that this summary statement applies to practically every type of operation-from the very light aircraft operator to the latest type high performance jet type of aircraft. The light plane operator does not want to be denied the use of any airspace in which he and his vehicle are capable of operating. Those operators who do not have instrument flight capability are naturally restricted by weather conditions. This limits the attainment of complete freedom in the use of airspace. Likewise, when airspace is reserved for the exclusive use of IFR controlled aircraft, without regard to weather conditions, a further limitation is placed on the VFR operator.

Operations conducted by VFR users of airspace cover a wide variety of different types of missions. Many fly for pleasure with minimum requirements for any service except for aeronautical pilotage charts and weather information. There are operations which cannot be conducted successfully without very good weather conditions, such as aerial mapping, pipeline and transmission line patrol, and for agricultural purposes. Minimum requirements of the system are entailed in these types of activity. On the other hand, more extensive operations are involved in conducting business and passenger carrying missions. Training, testing and acrobatics also have differing needs of airspace and services.

IFR operations also vary according to the particular mission of each airpace user. It is expected that general aviation activity will become a more significant factor in the IFR category in the immediate future. The types of aircraft and their equipment will range from the minimum equipped small aircraft to the latest high performance type with a full complement of the best equipment available. Their missions will range from short hops at relatively low altitudes to long range jet cross country trips. They will vie with scheduled air carrier and military flying for use of facilities and airspace. The military not only have operations comparable to air carriers but considerable activity which is peculiar only to military missions. These desires of airspace users bring to focus the overwhelming problem of providing for the equitable use of the available airspace without undue restriction on any single category of airspace user.

There is another category of user requirements which involves the availability of necessary aeronautical information for use by both VFR and IFR operators. Under this category, the Agency is charged with the responsibility of dissemination of weather information, field conditions, status of navigational aids, etc. While all pilots are responsible for the complete planning of their flight prior to takeoff, the Agency plays a very important part in this by making information available and assisting pilots by giving preflight briefings. After aircraft become airborne, the Agency provides in-flight information on changes in weather conditions, forecasts, winds aloft, and other data designed to assist the pilot in conducting his flight safely and efficiently. Flight following is provided and, when necessary, search and rescue procedures are inaugurated.

SECTION II
ATC/NAV System Principles

In consonance with the Federal Aviation Act of 1958, the FAA is responsible for the development and operation of a common system of air traffic control and navigation for both military and civil aircraft, as will best meet the needs of and serve the interest of civil aeronautics and national defense, excluding those needs of the military agencies which are peculiar to warfare.

The following list outlines the principles, and broad goals of the common Air Traffic Control-Navigation System:

1. A need for continuing ground control organization. Design to incorporate airborne collision avoidance capability.
2. Narrowing the wide gap between "see and be seen" flight and IFR controlled flight. Simplification of pilot proficiency requirements, equipment requirements, communication requirements, etc.
3. Principle of freedom of pilot desire, versus regimentation, permitting pilots to take advantage of aircraft characteristics, favorable winds and speeds as determined by pilot, not the ground.
4. System to be fail safe. Appropriate provisions made for continuous operation capability.
5. Navigation responsibilities to remain in aircraft. Navigational capability to fly to any destination or way points preselected or not, within the total navigable airspace with position indication at all times-with or without ATC.
6. Division of airspace which provides for "see and be seen" operations, ATC controlled operation and a mixture of the two. This latter must be kept to an absolute minimum.
7. Common system capability for area navigation and area type air traffic control throughout navigable airspace.

8. Provision of a single basic common system to satisfy all common system needs of all users. Requirements peculiar to warfare or above those necessary for common system operation at option of user.
9. System predicated on satisfying the needs of the human in a form readily assimulated by humans, versus training the human to fit the machine or equipment requirements.
10. Elimination of collision hazard.
11. Equipments required compatible in weight, cost, power consumption and size with benefits derived.
12. Total system simplicity with flexibility.

SECTION III

Analysis of the Problem

In the realm of electronics, there is a saying to the effect that "a problem well defined is already half solved." In this section an attempt is made to define the major portion of the total problem dealing with the ground-based air traffic control function as it is related to IFR operations. Whatever is done in this area will largely dictate the efficiency of airspace usage by all categories of air vehicles, helicopters to supersonic, IFR and VFR.

The responsibility for air traffic control by ground-based management cannot be fulfilled without the cooperation of all pilots. The system fails completely unless aircraft pilots cooperate and carry out flight maneuvers and change their intended flight path to the extent necessary to ensure safety as determined by the ground-based control office. The efficiency of the air traffic control service, as measured in terms of airspace utilization, depends on the number of air vehicles which can be safely accommodated in a given volume of airspace.

Basically the air traffic control system is not unique or totally different from other control systems. A familiar control system, now completely automatized, is the ordinary house-heating system. A thermometer measures temperature, it is compared with the pre-established desired minimum temperature level. Upon reaching this level, the furnace is adjusted to provide heat until the desired upper limit is reached. Such a control system normally provides a display, and controls for human override. Many control systems share common denominators in that whatever the product, the elements of (1) measurement, (2) comparison, (3) adjustment, and (4) checking the result are found as basic items. In order for a controller to carry out his responsibility, he must (1) have information on the relative position of all aircraft under his jurisdiction (measure), (2) be able to compare relationships with established minimums (compare), (3) adjust, by making flight path assignments to ensure separation (adjust), and (4) monitor the result of the flight path adjustment (check the result).

The effectiveness or tolerances of a system are related to the measuring capability. One cannot turn out a high quality bearing with a tolerance of one-thousandths of an inch (.001) unless measurement in that dimension can be made. The same is true with the ground based air traffic control system. The tolerances(1) depend on the measuring capability and become the separation standards which are applied by the air traffic control personnel. Unlike the single tolerance applicable in producing a high quality bearing, air traffic control must use a wide variety of tolerances ranging from approximately one-fifth mile or 1,000 feet vertically to 100 miles and more horizontally. This is necessitated by the wide differences in the system's measuring capability. Historically, the air traffic control system has utilized the most accurate of the measuring means available to the system. Since aircraft operate in three-dimensional airspace, let us briefly review the tolerances in three dimensions: width, length, and height.

First, taking the height dimension-it can be readily identified with the accuracy of altitude measurements; in short, altimetry. In addition to the accuracy of altitude measurement, the ATC system tolerance or separation minimum must include a reasonable allowance for normal deviations above and below the assigned level. The ATC system has always relied on this measurement as measured in the aircraft. It is the most efficient system tolerance in terms of airspace usage, permitting aircraft to utilize airspace within approximately one-fifth mile of each other.

The width dimension tolerance is generally referred to as lateral separation and, in many cases, is incorporated into the navigational route structure as route or airway widths. As in the case of the vertical dimension, the width dimension is determined primarily on the accuracy with which pilots can measure the position of their aircraft with relation to the desired track. In addition to the accuracy of position as indicated to the pilot, an allowance is made for reasonable deviations for normal conduct of flight. Here again, the ATC system depends mainly on the measurements as made in

(1) The word "tolerance" is used as an all-inclusive term synonomous with separation minima. and not in a strict mathematical sense. Actually, the measuring capability "tolerances" which dictate the basic dimensions, are combined with other considerations to form separation minima.

the aircraft. The tolerance or separation standards are very large, generally ranging from 10 miles at the lower altitudes to 32 miles at the upper flight levels.

Over the past several years, ground radar installations have provided ground crews with a higher accuracy of measurement than is available to the pilot. The ATC system has capitalized on this capability, and in many areas uses radar derived position information for a considerable improvement in airspace utilization. The 10- to 32-mile lateral separation is reduced to three or five miles. It should be noted, however, that where ground derived radar position data is used for lateral separation, the navigation responsibility must be assumed by air traffic control since the measuring capability is on the ground, not in the aircraft. It is necessary to provide the aircraft pilot with "steers" to initiate and maintain this type of lateral spacing.

The tolerance in the third dimension, length or longitudinal as it is called, depends primarily on the system's accuracy of measuring and displaying relative position of aircraft to the controller. In addition to the accuracy of position data, the frequency of updating, and the age of data displayed are factors which enter into the determination of the separation standards. In this dimension also, the ATC system has relied on the measurement capability as available to pilots in measuring their progress along their routes, except for the short period of time during which their progress may be directly observed by controllers at airport terminals. It is in this length or longitudinal dimension that the system measuring capability varies the greatest amount. The tolerance or separation standards vary from one minute in flying time to 30 minutes or more in flying time depending on the quality of the relative position of aircraft data available to the controller. With the advent of ground based radar, the measurement of aircraft relationships by ground derived information became far superior to the information as furnished by aircraft crews. In areas where the ground derived radar relative position data is available, only two distance standards of three and five miles are applicable.

In contrast to the single tolerance in producing high quality bearings, the complexity of the existing air traffic control system can be readily understood by comparing the single tolerance system with the variety of tolerances peculiar to each of the three dimensions involved in the use of the airspace. It is interesting to note the extremes in the present system measurement capability and compare the size of the airspace "boxes" for each. They range from a box in a particular radar environment 1,000 feet high, three miles wide and three miles long, to a box in a poor measurement environment two thousand feet high, 32 miles wide, and upwards of 100 miles in length, from approximately two cubic miles to 1,280 cubic miles of airspace. There are, of course, intermediate sized boxes used in between these extremes It is, however, a rare occasion when any single flight can be accommodated by a single box size for the entire length of the flight. This is a natural consequence of a system having so many widely differing tolerances through which traffic flows. Also, aircraft operations are random by nature which limits the attainment of minimum airspace boxes to those occasions where a reservoir of aircraft supply is available. This occurs primarily where queues or stacks of aircraft are waiting to depart or land at terminals.

It was stated earlier that many control systems have fundamental similarities, i.e., to measure, compare, adjust, and check the result. There is also a basic similarity in the flow of information in the control loop. A simple control loop is illustrated in Figure 1.

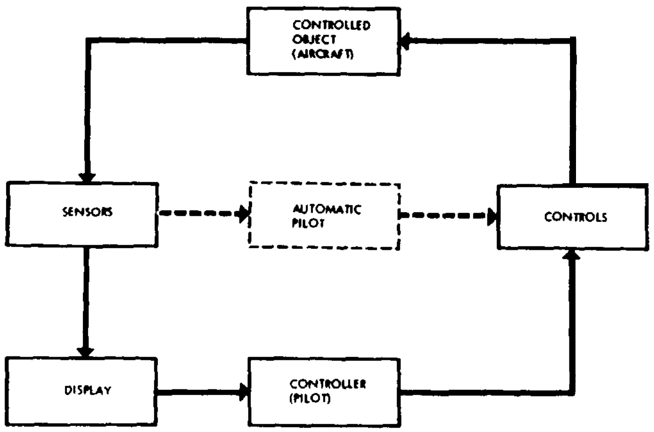

Figure 1.-Simple Pilot Control Loop.

This control loop is illustrative of controlling an aircraft in which the pilot is the controller. Controls are pedals, yokes, switches, etc., and the controlled object is the aircraft. The sensing devices

measure temperatures, rpms, the position of the aircraft, and other information which is portrayed to the pilot on a display. The pilot uses the information displayed to him to determine how he is doing and making any adjustments necessary to correct his attitude or line of flight. Communications are required to connect each block in the diagram. The communications between the pilot and the controls are mechanical, as are the communications between controls and the aircraft itself. A variety of communications techniques are employed

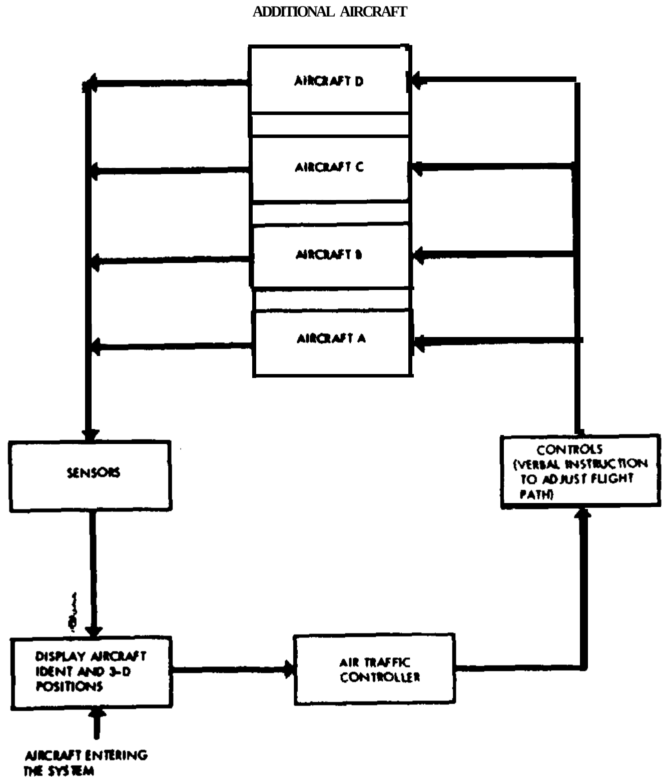

FIGURE 2.-Information Flow In Simple ATC Loop.

to collect information by the sensing devices-mechanical, electrical, electromechanical and others--all of which collect information needed by the human pilot to perform his function. The output of the sensing devices is normally integrated into a composite display; however, in this particular case, little progress has been made in developing a suitable integrated display. The information portrayed to the pilot by means of visual communication is used by the pilot to make control decisions, thereby completing the loop.

Figure 1 also illustrates the placement of automation in the control loop. It is in parallel with the human and receives its input from sensing devices and the output is directly connected to the controls.

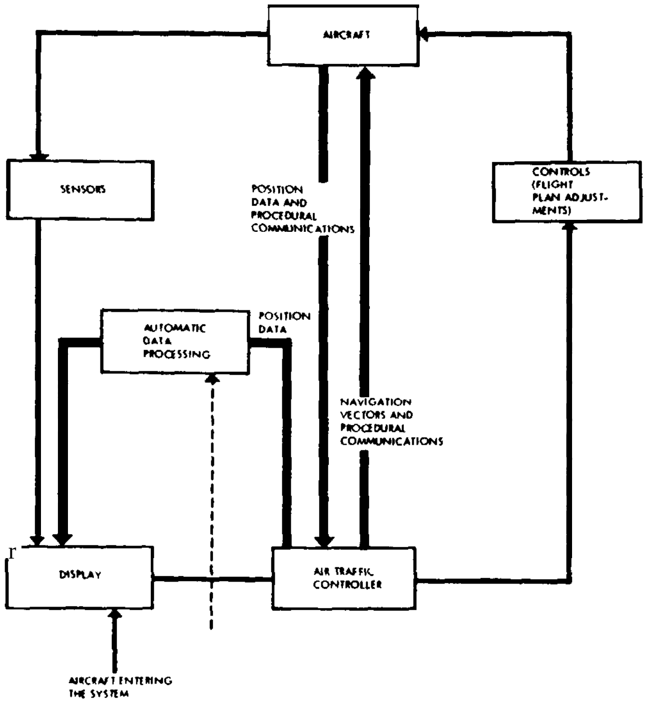

FIGURE 3.-Information Flow In Present ATC Loop.

The air traffic control loop is quite similar, except that it is a remote control system, and has as its objective the provision of adequate spacing between aircraft. Figure 2 depicts a block diagram of the air traffic control loop.

This loop differs because the controller cannot directly change the flight path of an aircraft. The only means available to the controller in accomplishing his function (keeping adequate spacing between aircraft) is to instruct or direct the pilot to deviate from his intended or desired flight path to the extent necessary to insure adequate separation.

As in all control systems which employ human controllers, we are interested in the informational requirements of the humans. In the air traffic control loop we must consider the informational requirements of both the pilot and the controller. First, the pilot needs information on the position of his aircraft with respect to the earth's surface and/or the common navigational structure. Second, the air traffic controller needs the intent, position and identity of each aircraft with respect to other aircraft and the earth's surface and/or the common navigational structure. The key to the effectiveness of the total system depends on how these informational requirements are fulfilled, and the accuracy of the information.

It is well to examine the flow of information in today's ATC operations, and see how it differs from the straightforward flow diagram. Such a diagram is depicted in Figure 3.

The double lines indicate the extra workload placed on the pilot and controller in attempting to overcome the deficiencies of our present control system. It can be seen that the prime function of the controller, that of monitoring aircraft relationships and adjusting flight paths as necessary, is overshadowed by his involvement in other duties. The nature of these duties is further discussed in the Appendixes.

Figure 3 also indicates the placement of the computer as used or proposed to be used in some facilities. The reason that problems arise in communications can be readily understood by comparing the flow of information in Figure 3 with that as shown in the normal control loop as depicted in Figure 2.

SECTION IV

ATC Requirements

Let it be clearly stated that the operational requirements of ATC have always been met, in some manner or another. Otherwise, ATC would not, and could not be performing its assigned job. Tbe real issue is the question of how well the ATC requirements have been met in the past, how well they are being met presently, and how well they will be met in the future. It should also be stated very clearly that ATC has no requirement for a specific piece of equipment. ATC has always used available equipments as will best fulfill a portion of the ATC operational requirements. Too often ATC operational requirements have been stated in terms of equipments, which in effect are preconceived solutions to operational requirements. As an illustration, there is no operational requirement for radar per se. There is, and always has been, a requirement for controller capability to monitor aircraft relationships and to adjust their flight paths. This requirement has been met without radar. However, radar introduced improved capability to monitor aircraft relationships with a much higher degree of accuracy than obtainable previously; therefore, it has been adopted. Radar has many limitations and only partially meets operational requirements and will undoubtedly be replaced someday with something better.

Operational requirements can be generally divided into two categories-the environmental requirements and the informational requirements. Good progress has been made in providing the environmental requirements. These relate to the adequacy of quarters, appropriate conditions of humidity, temperature, noise level, lighting, etc. It is a different story with the progress made in providing adequacy in the quality of the informational requirements.

It is perhaps true that there have been altogether too many statements or lists of operational requirements already submitted by many different people. Problems arise in efforts to consolidate and validate these often conflicting or contradictory requirements into a logical understandable uniform package. Many of the requirements have been related to a particular piece of hardware or to improvements in existing hardware.

As already mentioned, the basic requirement to provide ATC service is the capability to monitor aircraft relationships and to adjust aircraft flight paths as necessary to prevent collisions and to provide expeditious movement of aircraft. To be more specific, this capability involves information on aircraft intent, aircraft identities, and their three-dimensional position in airspace relative to each other and the earth's surface. It also involves a means of communicating flight path adjustments to aircraft pilots. Air traffic control has this capability, and has had it from the very beginning of the service. Admittedly, the information available may be very poor, that is, the aircraft position may be only a rough approximation, or the height dimension may be "somewhere between 4,000 and 8,000 feet," but in all cases the size of the box of airspace allocated for the protection of aircraft is commensurate with the quality of position information as available to the controller. It can be seen, therefore, that any statement of air traffic control operational requirements must be related to improving the present capability in monitoring and adjusting aircraft relationships. Such improvements fall into the following categories:

1. Improvement in the method of providing the informational requirements of the humans in the system.
2. Improvement in the quality of the information (accuracy, timeliness, etc.) provided by the system.
3. Improvement in both the methodology employed and the quality of information provided by the system.

The above category (1) improvements do not necessarily increase the capacity of the air traffic control system. Rather, they are aimed at placing the controller into a position wherein he can devote more of his time and attention to his control responsibility, and less time with the collection of aircraft movement data, updating displays, and coordination activities. Figure 3 in the previous section illustrates the involvement of the controller in this flow of information. It is a requirement that the flow of information in the air traffic control loop be modified to correspond with the flow of information as depicted in Figure 2.

Category (2) improvements involve statements of requirements which will increase the capacity of the system as measured in terms of airspace utilization. The use of radar, for example, provides increased capability in airspace utilization. All category (2) improvements involve better system measuring capability.

Category (3) improvements which involve better methods and higher accuracy in measurement capability show the most promise. Requirements listed in this area will, of necessity, be dependent on the degree of improvement desired. It is, therefore, essential that system capacity goals be established, which can then be reduced to operational requirements predicated on meeting such goals. Considering the statement of broad goals previously outlined, we will only amplify them with respect to system capacity. The capacity of the system depends on the volume of airspace which must be reserved as a cocoon surrounding each aircraft or, stated in another way, it depends on the number of aircraft which can be safely and efficiently accommodated in a given volume of airpace. We will arbitrarily choose a system capacity permitting aircraft to utilize airspace to their best advantage within the total navigable airspace with ATC intervening only as necessary to enforce a minimum spacing of one minute flying time or less. The minimum of one minute or less will actually be applied on a distance basis of from two miles to approximately 10 miles depending on speeds. The resulting capacity would come as close to satisfying user requirements as can be reasonably expected.

Having established a goal, the operational requirements to meet this objective can be outlined. Recognizing the relationships of the various elements of the system as outlined in the Analysis Chapter, we can amplify the basic requirements in a more qualitative manner as follows:

1. The navigational component shall :
   a. Provide navigational information to an unlimited number of aircraft (cannot be saturated), with useable accuracy of ± one-half mile throughout the useable airspace from the earth's surface to the highest useable altitudes.
   b. Provide navigational information to serve large areas without requirement of retuning or adjusting airborne equipment. (Goal - 200,000 to 300,000 square miles.)
   c. Provide a common reference to serve aircraft, air traffic control and air defense.
   d. Serve the navigational needs of all types of air vehicles, helicopters to Mach 4 aircraft.

2. The air traffic control element shall:
   a. Provide an integrated air situation display depicting aircraft positions (3-D) and identities with relation to one another in the horizontal plane and the common navigational reference, with an accuracy of ± one-half mile continually updated with no assistance from control personnel.
   b. Provide for independent controller selection of any volume of airspace as may be assigned for his jurisdiction.

The moment a value is placed on the quality of information needed by both the aircraft crew and the controller, the broad requirements are effectively reduced to very definitive detail.

With reference to the goals outlined, it is well recognized that at the present time there is no way of fulfilling the above requirements. It is also recognized that patterning the statement of requirements to coincide with present capability is a meaningless exercise. The operational requirements are based on a stated goal in airspace utilization capability. Admittedly, the goal discussed is an ambitious one, but not unrealistic when viewed from the standpoint of providing a service which will come as near to meeting user requirements as can be reasonably expected. Also, recognizing that the present collection of equipments and methods of providing ATC/NAV service has never had the benefit of a system design, a statement of operational requirements based on a stipulated efficiency in the utilization of the available airspace should prove useful to system designers. Whether the goal outlined herein, or less ambitious goals are ever met, is not as important as having established a proper course of direction to all improvement effort.

Of paramount importance is the consideration of the total system requirements prior to concentrated effort on individual components or elements which constitute only a part of the system. The total system approach is vital to insure the proper union and dovetailing of all interrelated elements into a coherent whole, as contrasted to developing "interfaces" to connect a variety of independent systems or subsystems. It is recognized that the various components of our present system do not meet the outlined future goals. In the area of navigation for instance, the VORTAC system in use today, best meets present requirements and will continue to serve for many years to come. However, one can never be satisfied with existing technology, but must always seek something better or progress will stop. Knowing the years of effort involved with producing any system that will be superior to VORTAC, we must start now,-at

the very time that VORTAC is becoming universally used,-to develop the next generation of equipments that will be in step with future airframe and engine developments.

A listing of operational requirements predicated on making the best use of current equipments available is difficult since it assumes intimate knowledge of equipment capabilities as well as equipment limitations. There are also dangers in stipulating what a piece of equipment should do, since it may increase the cost of the equipment all out of proportion with the benefits gained. Therefore, only a generalized statement with respect to the employment of existing equipments will be made.

Whatever configuration of equipments are employed for the express purpose of providing controller capability for monitoring aircraft (distance, or estimated future time) relationships, the following principles should be kept in mind:

1. The vital information of aircraft identity, 3-D position with relation to the earth's surface should be, insofar as possible, furnished to each controller without requiring his personal assistance.
2. Insofar as possible, each controller should be provided the vital information in 1 above within a volume of airspace which includes an area surrounding his assigned area to a distance equivalent to at least twice the separation minima applicable to such airspace. This is important, because by the ability to monitor those aircraft outside his area of jurisdiction prior to entering his area, the controller is automatically made aware of the flight details, identities, altitudes, and intent of those aircraft which will be of concern to him without the necessity of verbal discussions, hand-off procedures, and much unnecessary coordination type of communications.
3. The system must function on a 24-hour basis, day in and day out. Depending on the reliability built into all portions of the system, appropriate backup and standbys should be planned.

SECTION V

Measures of Effectiveness

The FAA is charged by law with the responsibility for providing a national common system of air traffic control and navigation for the efficient utilization of the navigable airspace, which will permit safe and efficient flight operations by all users of airspace. In order to provide a sound basis for FAA's programs, it is necessary to define standards of adequate performance which give consideration to the relationship between the public benefit provided by the system and the federal investment involved. Such standards are useful in evaluating the system as it presently functions, as well as in planning for the future.

In discussing the performance standards for the common system of air traffic control and navigation, it is necessary to differentiate between the dynamic type of air traffic control and the static type. For purposes of this discussion, static type of air traffic control is described as control by rules and regulations governing the conduct of flight, wherein the responsibility for safe separation is vested with each individual pilot. Obviously, it can only be effective in an environment wherein each pilot can effectively carry out provisions of the rules. While there is an urgent need to update current rules with realistic concepts, this discussion is limited to the dynamic type of air traffic control wherein aircraft flight paths are adjusted as necessary in a constantly changing dynamic air situation by direction of a responsible control agency.

Air traffic delays are often suggested as a measure of system performance. Delay figures alone, however, can be very misleading. The absence of delays may result from either an efficient system or the lack of system demand. On the other hand, substantial delays over a period of time may denote a very inefficient system or the saturation of a highly efficient system. Delay figures, to be meaningful, must be related to the demands placed on the system. Delays, other than holding for a landing sequence, are rather difficult to determine. For example, two aircraft desiring to fly identical paths must be separated by some fore and aft spacing. If the environment permits a spacing minimum of three miles, then the delay to the second aircraft would be about one minute; however, if the minimum applicable spacing is an estimated ten minutes flying time, then the second aircraft would suffer a ten-minute delay. In the latter case, however, the second aircraft will normally accept an alternate route or flight altitude level in lieu of the delay. The penalty paid as a result of selecting an alternate flight path is difficult to assess. Air traffic delays in the final analysis are inextricably associated with the permissible air traffic control separation standards which provide the key single measure of effectiveness of the total system.

The total ATC/NAV system measurement of effectiveness can be assessed by individual measurements made from carefully selected points within the total system. For this purpose the following chart has been prepared. It includes the measurements of present day effectiveness as compared with desirable goals at each measuring point. All actions aimed at improvements in capability should naturally fall somewhere between the present capability and the goals, with the cost being compatible with specific measurable benefits.

COMMON SYSTEM ITEMS TO MEASURE	PRESENT SYSTEM	PROPOSED IMPROVEMENT	GOALS
1. Air Traffic Control			
a. Lateral separation	With few exceptions. 16 miles between 15,000 and 24.000 msl 10 miles below 15,000 msl 32 miles above 24,000 msl		Not more than 2 miles in all navigable airspace
b. Vertical separation	1,000 ft. below 28,000 msl 2,000 ft. above 29,000 msl		Not more than 1,000 ft in all navigable airspace
c. Longitudinal separation	3 miles in limited areas. 10-15-30 minutes estimated flying time in most areas		2 to 10 miles dependent on aircraft speed in all navigable airspace
d. Does it provide aircraft position automatically	No		Yes

COMMON SYSTEM ITEMS TO MEASURE	PRESENT SYSTEM	PROPOSED IMPROVEMENT	GOALS
e. Does it provide aircraft identity automatically?	No		Yes
f. Does it provide aircraft relative height automatically?	No		Yes
g. Does it have * CAS potential?	No		Yes
h. All airspace	No		Yes
2. Navigation			
a. Single-system	No		Yes
b. Saturation point	DME limitation 1,000 aircraft		Cannot be saturated
c. Service-surface to highest useable altitude in all navigable airspace	No: limited to line of sight, cone of confusion overhead each ground facility		Yes
d. Useable accuracy in miles	Azimuth : 9 miles below 15,000 msl, 31 ml. above 24,000 Range: 1.35 miles below 15,000 msl 1.8 miles above 15,000 msl		± ½ miles in all navigable airspace
e. Average service area per ground installation	VORTAC 3,000 sq. ml.		250,000 sq. ml.
3. Air Defense			
Provide info on cooperative aircraft automatically	No		Yes
4. General			
a. Cost b. Personnel requirements c. Other			

*Collision avoidance system.

APPENDIX A

Navigation

The quality of the navigational service provided by the FAA to users of airspace has a direct relationship with the efficiency of the air traffic control service. Too often this relationship is not recognized. The navigation system is looked upon as a completely separate subject. It is true that there can be a navigation system without air traffic control, but there cannot be an air traffic control system without the navigation element, even if navigation were limited to dead reckoning. Unfortunately, the navigational element has received very little emphasis and is generally overshadowed by efforts which are more readily tagged with the ATC label. In addition, most observers do not associate the critical ATC terminal area problems with navigntion. They assume that only the airway widths in en route areas would be affected by improvement to the navigation system. Consequently, they do not believe it warrants much priority in time or effort. Many of the present day difficulties stem from the lack of adequate navigational capability by airspace users. Air traffic controllers are being saddled with more and more navigational duties in attempting to overcome basic system deficiencies. The relationship of navigation to air traffic control use of airspace is outlined in the section entitled "Analysis of the Problem" and will not be repeated here. However, the subject of navigation, as provided now and in the future, warrants further consideration, since it is so intimately related with modernization of the ATC system.

The Federal Aviation Act of 1958 not only describes the powers and duties of the Administrator, but also contains a declaration of policy which the Administrator shall consider in the exercise and performance of his powers and duties. Among these policy declarations is "the development and operation of a common system of air traffic control and navigation for both military and civil aircraft." Considerable progress has been made in the application of a single, or *common* air traffic control service; however, the attainment of a single or *common* navigation service has not moved forward. Perhaps one reason is the interpretation of what is meant by a "common system." Too often the direction has been in the sense of a "common melting pot" into which many "different" things are placed.

This paper will use the term "common system" in the context as used in the Civil Air Policy document. The following quotes are illustrative:

- The national interest dictates that a single, integrated system for air navigation and traffic control be developed. . . .
- The basic needs for such a system for air operations and the benefits resulting therefrom are analogous to those which early led to adoption of the standard gauge for rail transport.
- The single air navigation and traffic control system must satisfy the basic requirements of all civil and military air operations excluding special military needs peculiar. . . .

It will be noted that in all cases the common system refers to a *single* system of air navigation and traffic control.

Without dwelling on the past, the common system concept is of utmost importance to (1) automatically provide a common (single) reference for aircraft position as it applies to the pilot, air traffic control, air defense establishment, aircraft dispatchers, and other personnel having a need to know, (2) eliminate, or reduce the multitude of radiated navigational signals emanating from a variety and multitude of ground installations into the same airspace, (3) eliminate complexity and expense of operating and maintaining more than a single system of navigation.

There has been a growing tendency to place more and more of the navigational responsibility on the ground air traffic control organization. This so-called "vectoring service" is a method of overcoming the limitation of the navigational capability by aircraft crews, but is at the expense of added complexity in equipment, personnel, communications, and procedures. It may be necessary, if this trend continues, to consider the establishment of a separate group of "navigator" personnel to take over this responsibility and workload from the air traffic controllers.

Two of the principles and concepts outlined in this paper for the common ATC/NAV system are as follows:

Navigation responsibilities to remain in aircraft. Navigational capability to fly to any destination or way point, preselected or not, within the total navigable airspace with position indication at all times-with or without ATC.

Common system capability for area navigation and area type air traffic control throughout navigable airspace.

With respect to the former, complete freedom of navigational capability to fly randomly, or to any point selected by the pilot or controller, with precise position information available to the pilot at all times is required. The total navigable airspace means the useable airspace from the surface of the earth to the highest altitudes within the capability of the aircraft.

With respect to the latter, the use of designated routes within the total navigable airspace will be predicated on their contribution to the system in terms of providing (1) automatic lateral separation (2) segregation of opposite direction traffic (3) simplification of route description. They will be used in all high density areas to provide automatic separation of aircraft. Several narrow routes will be utilized between communities exchanging large numbers of aircraft to provide adequate capacity and to permit all aircraft to utilize desirable or optimum altitudes. Where the density of traffic does not warrant the use of designated routes, aircraft may fly direct, pressure patterns, or whatever route they desire. ATC will monitor all operations whether on an airway structure or not and adjust flight paths only when necessary for separation purposes.

A suitable navigational system should provide the capability to effect the segregation of en route traffic from terminal traffic. Routings can be changed, additional lanes can be implemented, or deleted, as traffic conditions change, without requiring any ground rearangement of navigation facilities.

Improvements in the navigational element of the common system will be considered in the light of its contribution toward attainment of :

1. Single common system.
2. Increased efficiency in airspace utilization (route widths).
3. Area navigation capability.
4. Navigational responsibility in cockpit.
5. Flexibility of routing.

It is emphasized that to gain the magnitude of navigntional precision discussed herein, we are referring to a future system. While recognizing that VORTAC best meets our present requirements, and will continue to do so for many years, we must also recognize that due to the long period of time (10 to 15 years) between conception and operational use of any new system, it is necessary to initiate appropriate action toward fulfillment of future requirements without delay.

APPENDIX B

Displays

Displays have been described as the heart of the ATC system. Most observers believe that the design of an appropriate display will solve most of the ATC problems. While there is no doubt that a good display is very important, it must be remembered that the display element is but one element in a series connected loop, and the total system effectiveness can be no better than the weakest component in the system. Equally important is the fact that a display is really a means of portraying whatever information is available. The display itself cannot improve the quality or accuracy of any of the information which is fed to the display.

It has been mentioned that the essence of a control system is to measure, compare, adjust, and check the result. In the air traffic control system, the purpose of the display is to provide an efficient means for the comparing job. It also provides a means of checking the result of any adjustments made. It has also been mentioned that the controller's job is to monitor aircraft relationships and to take action to adjust relationships as necessary. This is where the comparing comes in. He must compare the relationships of aircraft as presented by the display with the particular minimum spacing permitted under established rules and procedures applicable to the particular situation existing at the time. There are, of course, many different minimums, each directly related to the quality of the information on aircraft relationships as displayed.

In areas where the system provides approximate position data, updated infrequently, aircraft are separated by increments of time. It is, therefore, necessary that the display show time relationships of aircraft. The technique used in the employment of time separation can be described as the extension of an airspace sampling process, wherein certain selected spots on the earth's surface are chosen as sampling points. The expected use of airspace by aircraft over, or close to, such points (normally fixes over which aircraft can detect their position with some degree of accuracy) is recorded.

By estimating the time of passage of each aircraft over the various preselected points, a display is generated which portrays the estimated future time relationship of all aircraft in the system. This future time relationship is, of course, always an estimated relationship. The estimated times are revised as necessary, based on the information available on the past history of each aircraft. An examination of the display will provide information on (a) the airspace usage in the immediate past, (b) the current airspace situation, and (c) the future anticipated usage of airspace, all with relation to clock times at the selected sampling points. Anticipated or estimated time relationships of aircraft are thus made known to the controller.

In areas where the system provides a relatively high quality of aircraft position data, updated frequently, aircraft are separated by increments of distance. In this type of environment, the display must show distance relationships of aircraft. A display of this type shows highly accurate data on aircraft positions, with no requirement for estimated position data, since the frequency of updating is such that the distance the aircraft travels in between position reports can be effectively incorporated into the separation standard. This protects against false position data which might create hazardous conditions.

A proper ATC display, whether it be a distance relationship or time relationship type, should provide for a volume of airspace to be portrayed for each controller, which includes an overlap area equivalent to at least twice the applicable separation minimum around the perimeter of the area of individual jurisdiction and responsibility. Each controller is thus continually informed of data on additional aircraft entering his area of jurisdiction.

There has been much discussion on the need for two types of displays, namely, a planning display and another one used as the immediate situation control decision display. The planning display is normally described as one used to organize the use of airspace and is generally related to the use of time separation standards. Likewise, the immediate situation control decision display is always related to the use of distance separation stnndards. In reality, then, if air traffic control uses a large volume of airspace for separating aircraft, it is considered as organizing the use of airspace, and if they use a very small volume of airspace in separating aircraft it is something different. Contributing to this belief are the shortcomings of the displays. In a time separation environment the aircraft intent, identity, three-dimensional position and time relationship with other aircraft. are all shown on the display. This is the planning, as well as the immediate situation display for employment of time separation. In a distance separation environment, the primary display only shows the horizontal distance relationships of aircraft targets. An auxiliary display must be used to fill in all the missing display items. Normally a version of the time relationship displays is used to fill this need. No doubt this deficiency of the distance relationship display contributes to the philosophy of the so-called planning display.

In summary, the basic informational needs which a display should portray to the controller in areas necessitating the employment of time separation are:

1. The actual and/or estimated clock times of all aircraft relative to reaching or passing established reporting points of the navigational structure.
2. The identity (radio call) and altitude or flight level of each aircraft.
3. That portion of pilot's intent (flight plan) as is applicable to his area of jurisdiction.

For areas providing a sufficiently high quality data permitting the use of distance separation, the basic informational needs of each controller are:

1. The identity (radio call) and x, y, and z positions of each aircraft with respect to each other and to the navigational (airways) structure and/or the earth's surface.
2. That portion of pilot's intent (flight plan) as is applicable to his area of jurisdiction.

Applicable to both types of environments are these additionnl requirements:

1. For those controllers responsible for a volume of airspace which includes a terminal, a display showing a chronological listing of arriving and departing aircraft.
2. A volume of display which includes a perimeter area 10-15 miles beyond his area of jurisdiction in a distance separation environment, and 30 minutes flying time beyond his area of jurisdiction in a time separation environment.

APPENDIX C

Procedures

Procedures can be very simple and efficient or they can be very complicated and complex. Simple and efficient procedures go hand in hand with a fundamentally sound and efficient basic system. However, when procedures are used as a crutch to support and make up for the deficiencies of a poorly designed system, they become complicated and voluminous.

Prior to the inauguration of the air traffic control service, it was necessary for some group to determine the manner or method of proceeding with the job. In this way ATC procedures were born. They always result from a study of what information can be made available, how it is made available, and what tools are available to accomplish the mission.

ATC procedures are continually in a process of modification and amplification, in an effort to reflect the rapidly changing demands due to advancements in aircraft performance, development of new equipments, and the ever increasing special types of airspace user requirements.

The basic ATC procedures are built around the application of separation standards. There are many different minimums in use, each dependent on the quality of information a particular environment produces. It is, therefore, necessary to establish procedures for the use of each minimum, describing the particular circumstances under which each minimum applies, and the actual method of application, using prescribed phraseology. It can be seen that a considerable volume of procedural instructions could be eliminnted if the basic ATC system provided a uniform quality of control data throughout the system.

Procedural complexities arise from attempts to overcome basic system deficiencies by the procedural route. The volume of these special procedures has been growing at an alarming rate, and shows no sign of tapering off in the immediate future. While it is recognized that procedural solutions are a necessary expedient, too often the basic cause of the deficiency is not determined or corrected. This process results in a very weak basic machine supported and hung together with bailing wire, temporary "fixes" one on top of another.

A basic requirement, one that was just as valid the first day of ATC as it is today, is the acquisition of three-dimensional position and identity of each aircraft in the ATC system. How the system provides this information has changed considerably since the first day, but the day when the system provides it automatically is still not in sight. It has always been the role of procedures to solve this problem. In a radar environment, several methods of identification procedures have been developed. DME provides another procedural method of identity. More procedural identification methods will be developed with the use of ATCRBS. The acquisition of altitude data will also require a procedural solution. The main problem with procedural solutions is that they require the participation of either the pilot or the controller, usually both, thus adding to the communications load and bookkeeping functions. Here again, it can be seen that a system designed to automatically fulfill a basic requirement will eliminate many time-consuming procedural crutches, relieve both pilots and controllers of extra-curricular activities, and ease the loading on communications channels.

Heavy dependence on procedural solutions will be involved in efforts to take care of such items as CVR operations, segregation of terminal operations in accordance with aircraft performance, special corridors and tunnels for special uses, and to facilitate positive control operations at terminals and en route areas. Many of these will evolve from experimentation and tests under simulated and live conditions.

A continuing effort to ease the procedural load on controllers is vital to system improvement. Consideration should be given to modification of ATC clearance procedures. The original clearance normally issued to destination airport today primarily serves as a verification of the pilot intent. It is simply an authorization by ATC to proceed. Incorporated in such authorization is the tacit understanding that no other known air traffic will be permitted to approach the aircraft of concern closer than certain specified minima. It does not imply that airspace is reserved or conflict free to destination or that the aircraft being cleared has prior rights to such airspace. Recognizing that the present day long range clearance is primarily a verification of pilot intent, it may be possible to make

this verification through the operations office to the pilot prior to boarding his aircraft. The pilot would then get his proceed clearance from the control tower along with necessary muting instructions to get the aircraft along his intended path of flight. Thereafter no more clearances would be issued by ATC. Instead, instructions to adjust the flight path as dictated by traffic conditions would be issued. The clearance limit would always be the filed destination airport. The aircraft's flight path may be adjusted vertically, laterally, or even by holding maneuvers, if dictated by traffic conditions, but these do not constitute a change in the clearance limit, and no instructions are issued unless an adjustment is necessary to maintain appropriate separation, or to facilitate expeditious movement of the aircraft. Carrying out this concept will eliminate many useless clearances issued today. By useless, we mean those clearances which are never carried out, but cancelled or superseded by additional clearances which void those previously issued.

Compulsory verbal position reporting procedures will be modified in those ATC environments producing aircraft position reports by means of radar or beaconry when suitable means of associated aircraft identity (radio call) are provided.

APPENDIX D

Automatic Data Processing

Automation is a glamorous subject and is being hailed as a popular solution for air traffic control. Gone are the days when the digital computer was known as the idiot box. This label stemmed from the fact that it can do nothing without first having a human to break even simple problems to elementary ones and twos. It was pretty well understood that a computer's total ability is limited to addition, subtraction, and comparison of numbers.

Computers are many things to many people. There are many automatic control systems which are not generally associated with computers. For example, the simple thermostat which controls home heating is taken for granted, although it is actually an application of an analogue computer. A governor on a motor or engine is another example. In these examples, automation takes over the job formerly performed by people. Their success depends on the ability of the sensing element to directly actuate the controls of the system.

The FAA has initiated the use of digital computers, but not in the sense of automating the ATC function. Instead, their primary employment is for display generation and use as a communications link. Their use has been limited to those areas producing a poor quality of aircraft position data wherein time separation standards are employed. No reduction of separation standards are realized or expected since computer processing of data cannot improve the quality of the data entering into the machine. Further, as every hi-fi fan knows, the quality of the weakest link in a system governs the quality of the output. Since the weak link in this case is the quality of aircraft position data, sophistication of any other portion of the system is not apt to pay significant benefit. The function of air traffic control, whether it be en route or terminal, is monitoring aircraft relationships and adjusting flight paths as necessary to prevent hazards of collision and to expedite their movement. No serious consideration has bean given to taking the controller completely out of this function. Practically all proposals for ATC modernization discuss using computers for such jobs as display generators, passage of control data from one display or facility to another, taking over controller bookkeeping duties, radar hand-offs, etc. They are primarily aimed at enhancing the controller's ability to monitor aircraft relationships. Since computers cannot by themselves serve as sensing devices in the measurement of aircraft relationships, the question arises, why cannot the output of whatever sensing devices are used be directly displayed without the necessity of processing by computers? This cannot be done at the present time because we do not have appropriate sensing devices. However, with proper emphasis on the design of appropriate sensing equipment, there seems to be no reason why the output of sensing devices could not be integrated and directly displayed.

Of grave concern is the use of terms such as automating ATC functions, when in reality there is no automation gained. Replacing a controller's pencil with buttons, lights, and keyboards does not in any way denote automation. Nor does it denote a reduction of controller bookkeeping duties; in fact, extreme caution must be exercised to guard against loading the controller with so many extracurricular activities associated with computer input and output devices that his time and concentration will be seriously diverted from his vital function of monitoring aircraft relationships on his ATC display.

The prime requirement is to *automatically* provide the controller with the information he needs to properly monitor aircraft relationships. By automatically, we mean without the assistance of the pilot or the controller. Proposals to automate must be judged on how well this task is accomplished.

APPENDIX E

Air Defense and Air Traffic Control

The Semi-Automatic Ground Environment (SAGE) was established to enhance air defense capability. Basically, the environment is intended to provide air surveillance within areas of concern, particularly the air approaches to the nation, in order to detect aircraft with hostile intent. When hostile aircraft are detected, the system further provides information necessary to evaluate the threat and conduct the air battle. This means a determination of the size, composition and deployment of enemy forces, the prediction of possible targets for threat evaluation, the availability and deployment of various types of weapons with a prediction of intercept points from weapon sources, and the control of such weapons for the conduct of the air battle.

The air surveillance portion of the system of necessity is accomplished by noncooperative means-hence the choice of radar. All aircraft targets picked up by the radars are classified as unknowns until they can be identified as either friendly or hostile. If and when hostile aircraft are detected, a form of control loop goes into action. It has as its objective the destruction of hostile aircraft. The ADC controller is provided with a display showing the three-dimensional position of hostile aircraft, estimated location of intercept points from certain weapons or weapon platforms, and the location of weapon carriers. The controller's job is to direct the weapon carrier to a position in airspace where the kill can be accomplished. This weapon control system must be exercised in peace time to insure readiness.

The weakest link in the air defense setup is the identification of unknown aircraft which are detected by the radar nets. The air traffic control system provides information on the estimated position of aircraft on which they have knowledge. However, in many cases the quality of this information is so poor that correlation with radar targets is quite impossible. Very often interceptor aircraft are dispatched to establish identity of unknown targets.

Recognizing the nation's air defense requirements, along with the requirements of air traffic control, there are three areas in this total system concept where the informational requirements of the human operator must be considered. First, there are the information requirements which the pilot of each aircraft needs in order to effectively carry out his intent or mission. This calls for continuous, accurate aircraft position information with respect to a common reference. The second area is the informntion requirements of the air traffic controller, which are continuous, accurate position and identity of each aircraft with relation to the same common reference. The third area is very similar in that our nation's air defense establishment needs aircraft position and identity in order that it may immediately weed out friendly aircraft and concentrate on the unknown targets picked up bv its noncooperative air surveillance system. The long range objective is a system which will fulfill these three areas of information requirements automatically and with a high degree of accuracy. By providing automation in these critical areas, the human element can be utilized in a role where human superiority over machines is well recognized-exercising judgment.

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